Silicon Micromachined Waveguide Components at 0.75 to 1.1 THz

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***Abstract*—Silicon micromachined waveguide components operating in the WM-250 (WR-1) waveguide band (0.75 to 1.1 THz) are measured. Through lines are used to characterize the waveguide loss with and without an oxide etch to reduce the surface roughness. A sidewall roughness of 100nm is achieved, enabling a waveguide loss of 0.2dB/mm. A 1THz band-pass filter is also measured to characterize the precision of fabrication process. A 1.8% shift in frequency is observed and can be accounted for by the 0.5deg etch angle and 2um expansion of the features by the oxide etch. The measured filter has a 13% 3dB bandwidth and 2.5dB insertion loss through the passband.**

I. INTRODUCTION

Silicon micromachining has emerged as a viable technique for manufacturing terahertz waveguide circuitry [1] [2]. Deep Reactive Ion Etching (DRIE) of silicon has been used to demonstrate a wide variety of components including filters, hybrid couplers and receivers [3]. By being a batch-fabrication process, tens to hundreds of pixels can be manufactured at once, with precision and uniformity comparable or better than traditional CNC metal machining. This fabrication technology is significantly more competitive at higher frequencies where the etch-times are shorter, reducing the sensitivity to the selectivity of between the silicon and mask and fabrication tolerances can exceed that of CNC machining. This fabrication technique is currently being pursued to facilitate the development of heterodyne receiver arrays for future astrophysical and planetary missions as well as for reducing the cost of radar imaging arrays [4].

In this paper we present for the first time Vector Network Analyzer (VNA) measurements of waveguide loss, band-pass filters and 3dB hybrid couplers at 0.75 to 1.1THz. The hybrid is measured with two ports terminated, requiring compact integrated waveguide loads, so a method for casting these loads directly into the waveguide structure will be presented.

II. FABRICATION AND ASSEMBLY

Figure 1 shows the split block configuration and the fixture for measuring the silicon micromachined components. Each piece is 5x5 mm in size, which is just large enough to support the test features. Alignment between the silicon and the waveguide flange fixture is achieved through silicon compression pins [2]. These pins have alignment precision better than 2 μm, and the tolerances between the flange pin and the compression pin alignment feature result in an overall tolerance of 10μm between the waveguide and measurement flange. We expect a return loss greater than 30dB at these frequencies with this alignment scheme.

The waveguide components are fabricated on a silicon-on-insulator (SOI) wafer, where the device layer is 130μm thick and the handle is 320μm. The structures are formed by DRIE of the device layer down to the buried oxide layer. To reduce the roughness of the finished waveguides, 2μm of thermal

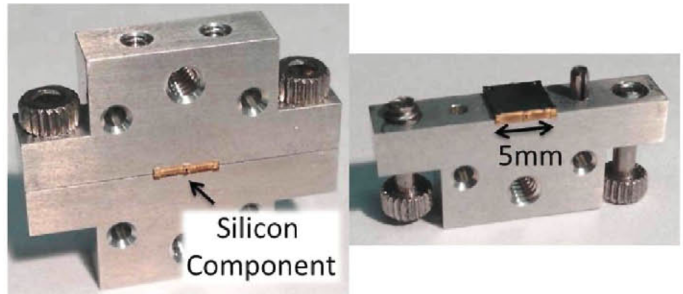

Figure 1: The housing for the silicon micromachined components.

oxide is grown and then removed with a buffered oxide etchant. Finally, 2μm of gold is sputtered to metallize the structures.

III. MEASUREMENTS

Being a crucial aspect of the sensitivity of any terahertz receiver, the waveguide loss is first characterized. Shown in the top of Figure 2, the waveguide loss without any additional steps to reduce the roughness exhibits high loss, 0.6-1 dB/mm. Because this is five times higher than CNC machined waveguides, the thermal oxide growth and removal step is added to the process. This reduces the loss to less than 0.25 dB/mm across the band.

The waveguide thru pieces were cleaved along the center waveguide so that the roughness of sidewalls could be measured. The RMS roughness of the sidewalls is reduced from 335nm to 100nm with the oxide etch.

Band-pass filters are structures highly sensitive to fabrication imperfections and an excellent diagnostic for the process. In particular, etch angle and the effect of the oxide etch are of concern. Figure 3 shows the measurement of an E-plane split band-pass filter, initially designed to be centered at 1THz with an 11.7% 3dB bandwidth. The resulting filter is centered at 0.982THz with a 2.5dB insertion loss across the 13.1% bandwidth, 1.8% off from design. By including a 0.5deg etch angle and a 2 μm of enlargement of the filter cavities due to the oxide etch, the simulation can be brought into very close agreement, as shown in the dotted lines of Figure 3.

IV. SUMMARY

Silicon micromachined straight-waveguide sections and band-pass filters have been fabricated and measured at the WM-250 (WR-1) frequency band to evaluate the process for future terahertz receiver development. Applying a thermal oxide growth step followed by a wet-etch reduces the sidewall roughness from 335nm to 100nm and the waveguide loss from 1dB/mm to 0.25dB/mm, and is now comparable to metal machined waveguide losses. Fabrication of a band-pass filter showed only a 1.8% shift in frequency which could be

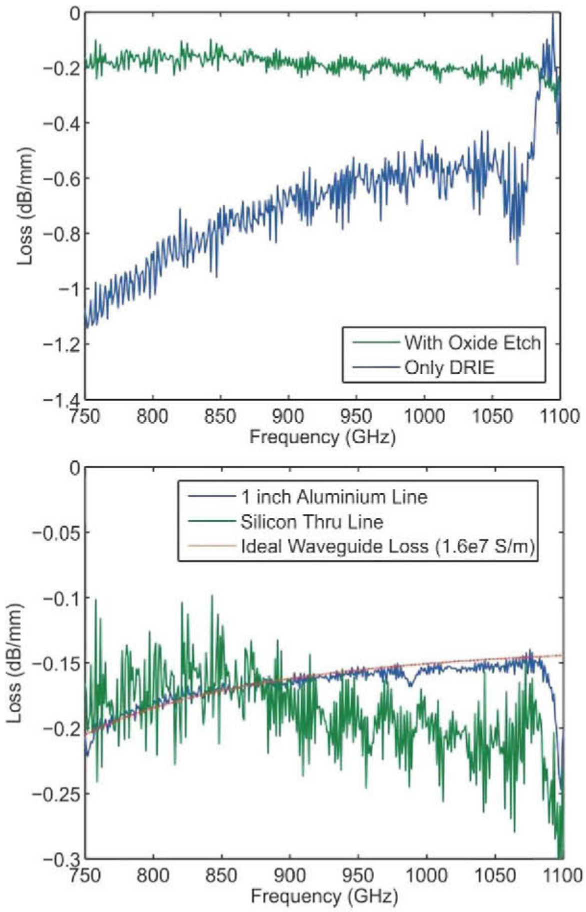

Figure 3: (Top) Waveguide loss of the silicon micromachined lines with and without the thermal oxide grown and etched to reduce the roughness. (Bottom) The smoother silicon waveguide compared to a metal machined line length and the expected waveguide loss. The deviations above 1025GHz are due to calibration errors.

accounted for by including the etch angle and feature expansion into the simulation.

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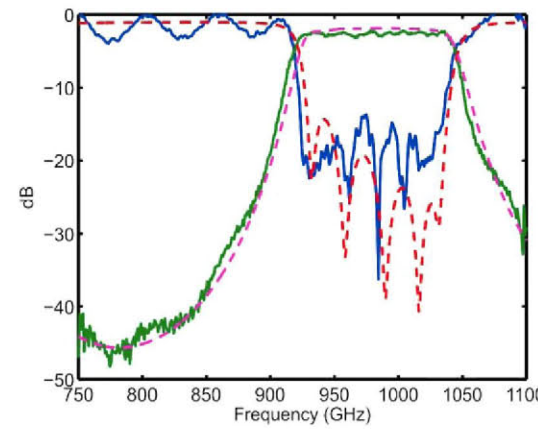

Figure 2: Measured S-parameters of the 1THz band-pass filter. Dotted lines indicate the simulation result incorporating the 0.5deg etch angle, 2um expansion due to the oxide etch and the 100nm sidewall roughness.

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